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Lubrication

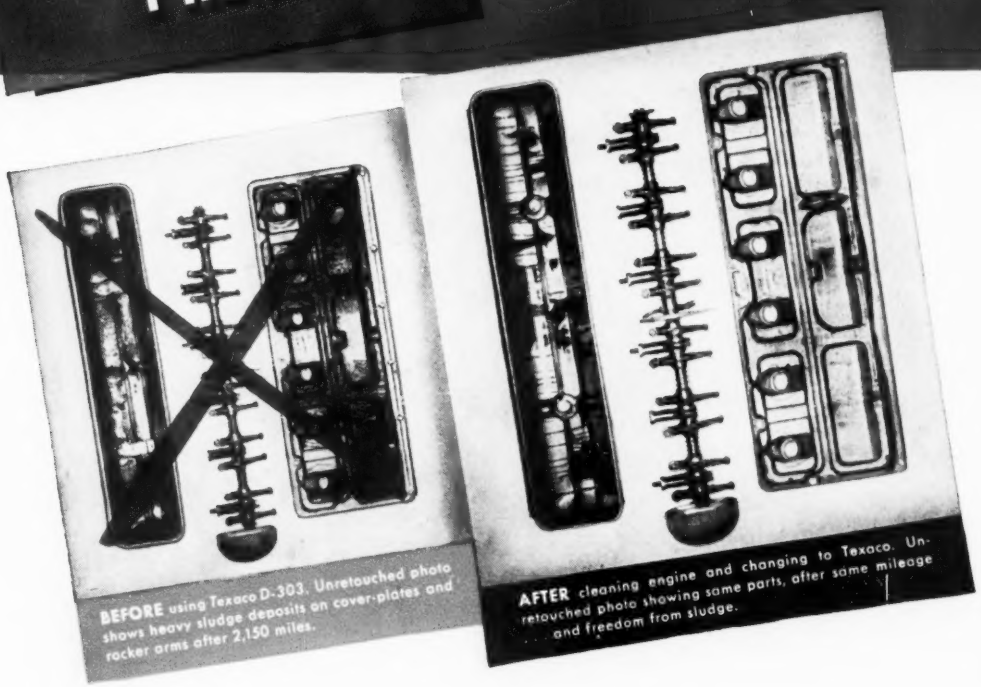
A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Present-Day Operation of Truck and Bus Gasoline Engines

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

PHOTOGRAPHIC PROOF THAT ENGINES STAY 3 TIMES CLEANER



BEFORE using Texaco D-303. Unretouched photo shows heavy sludge deposits on cover-plates and rocker arms after 2,150 miles.

AFTER cleaning engine and changing to Texaco. Unretouched photo showing same parts, after same mileage and freedom from sludge.

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TEXACO Lubricants and Fuels

FOR BUS AND TRUCKING INDUSTRIES

LUBRICATION

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Present-Day Operation of Truck and Bus Gasoline Engines

COMPARATIVE statistics based on truck and bus operations in 1917 vs 1942 tell a significant story of progress in production, operation and maintenance. *In 1917 only 326,000 trucks were in use in the U. S.; today there are over 4,911,000. Today trucks link war production plants together so effectually that the war assembly line is often over a hundred miles long. *Statistics indicate further that trucks move 65% of the freight into, and 69% out of 741 war plants. Trucks use 21% of the gasoline consumed in the U. S. Nor does this vast assembly of motorized equipment detract from the value of rail transportation; instead it is supplementary thereto. Even the railroads themselves appreciate this fact — they operate over 94,000 trucks and several thousand buses in the handling of short-haul freight and passenger traffic. In this way they keep the rails open for fast freight, military and through passenger traffic.

The American will is to find a way. It used to be by trial and error. Today, it is developed by research laboratory study. Fortunately, the automotive industry made good use of the research laboratory, the ultra-microscope of the physicist, the test tubes of the chemist, the alloys of the metallurgist. All stand this vital industry in good stead now when transportation must not fail, when the automotive engineer is faced with the restriction of materials which became so essential as his industry grew up. But, being a versatile personage, he has not faltered, he just turned back to the laboratory for new ideas. Then he tried them in that acid test—road service. That he has succeeded is evidenced by the fact that our some five million trucks and buses are still running, and will stay on the road for the duration. The maintenance foreman will see to that, even though he may gripe if a little knock develops in his engines.

Over 146,000 buses are operating in this country today and the importance of the service they are rendering increases almost hourly. With the sharp reduction in passenger car travel as a result of curtailed production, material shortages and gasoline restrictions, more and more people are turning to buses as a means of transportation. The most important service being rendered by buses today is the transporting of our factory workers engaged in producing America's vital war materials to and from their homes.

All connected with the successful operation of these vehicles are contributing to the war effort. There is no doubt as to the part played by the oil refiner whose job it is to supply the fuels and lubricants so necessary for the proper and continuous operation of these

*Motor Truck Facts—1942 Edition Automobile Manufacturers Association.

vehicles. Present-day commercial requirements, however, are obviously of secondary importance as compared with military demands. Therefore, the modern heavy duty gasoline engine used in buses and trucks with its increased power and high overall performance must be adjusted in order to continue to obtain the benefits built into the equipment by painstaking efforts of recent years.

Fleet operators may rightfully ask what can be done to insure satisfactory operation as well as to conserve equipment with replacement materials becoming unavailable. In anticipation of just such a query, engine manufacturers and oil companies have conducted investigations both singly and collectively into this vital problem. Fleet operators themselves have discovered many new methods of caring for their equipment. Much valuable information has already been made available to the industry. Preventive maintenance and material conservation have assumed new importance. The oil refiner has contributed his share in continuing the high quality of his products while carrying on unceasing research for new and better fuels and lubricants.

FUELS

The fuel most commonly used today in commercial vehicle service is gasoline. By careful fractionation and control during the process of refining it is manufactured to give the fleet operator quick engine starting, rapid warm-up, satisfactory power and economy. There are three grades of gasoline available to the bus and truck operator, namely premium, regular and third grade.

Estimated gasoline production* in these grades for 1941 totaled 96% of the total gasoline produced, the remaining 4% constituting aviation gasoline. Of this 96%, the regular grades comprised 76% with premium and third grades comprising the remainder in equal proportions. Now, with a total and unconditional war on our hands, the role that aviation and motorized equipment must play demands first consideration with regard to the fuels they require. With the estimated demand for 100 octane aviation gasoline increased far above the 1941 peak production of 50,000 barrels per day, the oil refiners have been called upon to strip their motor fuels of all possible aviation fuel components. This as well as other curtailments in the refining operations have an effect on motor fuel base stocks, chiefly with respect to possible lowering of the octane value.

Immediately the question arises, "How about making up for these deficiencies in octane by adding more tetraethyl lead?" Unfortunately wartime conditions have required drastic restrictions on certain supplies of raw materials for non-military uses. In the case of tetraethyl lead, curtailment of lead, chlorine and alcohol used in its production have necessitated reduction of the allocation of this vital fluid to refiners for use in civilian motor fuels.

Drastic reductions in octane value have not been necessary to date but in most cases there has been some adjustment downward. At the moment it appears that the octane ratings have been stabilized at present levels and some authorities have ventured an opinion that ratings probably will not fall very far below these values.

Fortunately the properties of gasoline, other than its antiknock quality, have not been affected materially. It still retains the proper volatility so necessary in an engine for ease of starting, rapid warm-up, acceleration and resistance to vapor lock. Likewise, those qualities which inhibit corrosion of metals and which prohibit the formation of gummy deposits that clog carburetor jets and stick valves and piston rings have not been impaired. The slight reduction in antiknock quality or octane rating may have made itself known by detonation or knocking. At the same time some power and economy loss may have resulted but the extent to which these factors are observed depends chiefly on the octane requirements of the engine and the ignition timing employed for the fuel used previously.

Difference Between Detonation and Pre-ignition

Considering detonation, it may be well at this time to distinguish between this phenomenon more commonly known as knocking and pre-ignition which, although allied with detonation in some respects, should not be confused or considered interchangeably with it. Detonation occurs in a spark-ignition internal-combustion engine during the process of combustion of the air/fuel mixture within the cylinder after ignition at the spark plug has taken place.

Combustion normally starts at the spark plug and the flame front spreads toward the unburned portion of the charge. The high temperature of the burned portion compresses this unburned charge resulting in the latter increasing in pressure and temperature until self-ignition occurs before the flame front reaches it. Violent pressure waves are then set up within the combustion chamber with a resultant knocking noise known as detonation.

Pre-ignition means the initiating of combustion before and by some means other than the regularly timed spark at the plug. It is gener-

*Symposium—Commercial Vehicles and Lower-Octane Fuels by Wm. H. Hubner, Director, Refinery Technology Division, Ethyl Gasoline Corp. Pub. in S.A.E. Journal, April, 1942.

ally caused by localized overheating at some point such as exhaust valve heads, spark plug electrodes, high spots on the piston or cylinder head or carbon deposits. It is not improbable that some supposed detonation may actually be traced to pre-ignition of the combustible mixture by hot spots caused by clogged cooling water passages; excessive retardation of the spark timing causing increased combustion chamber temperatures; insufficient or improper cleaning of spark plugs and combustion chambers permitting incandescent carbon deposits to form; or the employment of improper spark plug gaskets or the complete absence thereof preventing proper heat transfer.

Fig. 1—Top view of an automotive piston showing erosion of metal caused by detonation.

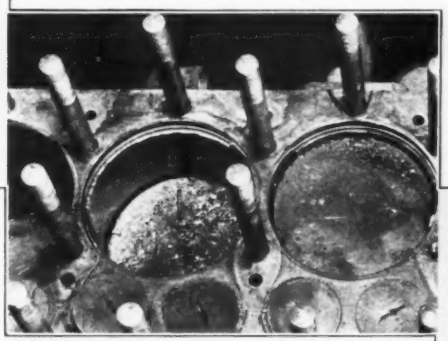


Fig. 2—Looking down on an engine cylinder block showing effects of detonation on piston heads and cracking at top of cylinder liner.

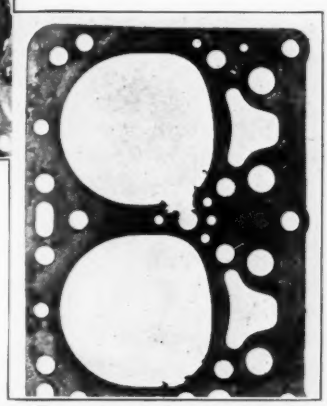


Fig. 3—A typical automotive cylinder head gasket showing failure due to detonation.

Fleet operators commonly adjust the static spark setting until a trace of "pinging" is heard under full throttle operation. As a consequence any use of a fuel having a lower octane value than that employed when the spark timing was initially adjusted will result in increased knocking or detonation with attendant losses in power and economy. Aside from these performance losses, continued operation under severely detonating conditions has been known to cause failure of such engine parts as cylinder head gaskets, pistons, spark plugs, valves, etc. The illustrations show the types of failures that have occurred in engines permitted to detonate excessively and for prolonged periods of time. See Figs. 1, 2 and 3.

Usually the cylinder head gasket is the first part to suffer as a result of this condition. Furthermore, a new gasket may not be readily obtained due to the priorities on the steel and copper employed in gasket manufacture, so more attention to the conservation of those on hand is necessary. The damage caused by detonation within the engine usually involves erosion of the metal. In the case of pistons this generally occurs at the edge of the head surface. This erosion of metal may extend to the top piston ring and not infrequently to the cylinder wall and liner. It is readily apparent that unjust demands are made on the lubricating oil in these areas. Spark plugs suffer enlargement of gap clearances due to this metal erosion while portions of the porcelain insulation chip and break away, destroying proper spark conductance to the electrodes. Since detonation is accompanied by high temperatures and pressures, valve warpage, burning and in some cases valve head breakage have been experienced.

The readiest solution to the detonation problem is the use of a fuel of higher octane rating, if available. Because of the higher cost of these fuels the commercial vehicle owner must make his ultimate decision on the fuel to employ based on the final cost per mile of operation. On the assumption that the fleet operator does not care to use the fuel with a higher rating it becomes necessary to resort to mechanical adjustments to compensate for this octane reduction. Mechanical adjustments for this purpose include:

1. Adjustment of ignition timing.
2. Adjustment of carburetor mixtures.
3. Lowering of compression ratios.

While the first two corrective measures require only expert mechanical treatment and periodic check-ups, the latter change may entail modifications in engine design and parts replacement; the accompanying costs of which the thrifty fleet operator is always conscious. Let us examine briefly the factors involved in the foregoing adjustments that may be required to adapt some of the commercial engines to the fuels now available.

Ignition Timing

It is common knowledge that detonation in

an engine can be eliminated by retarding the ignition timing. However, while this adjustment is comparatively simple to make, some loss in engine power and gasoline economy may result with the exact amount of each varying from engine to engine.

Reviewing some of the fundamentals involved in engine performance, it is known that the maximum power of an engine is developed at some definite ignition timing. Curve A in Figure 4 shows the typical relationship that ordinarily prevails between engine speed and ignition timing for maximum power. Naturally there will be some variation for different engines and different fuels. If the spark is advanced or retarded with respect to Curve A at any particular speed, the engine will produce less power. Curves A′ and A″ show the spark retarded from Curve A to such an extent as to cause power losses of about 1% and 5% respectively. C-C-C-C is a typical automatic spark advance curve for the engine in question.

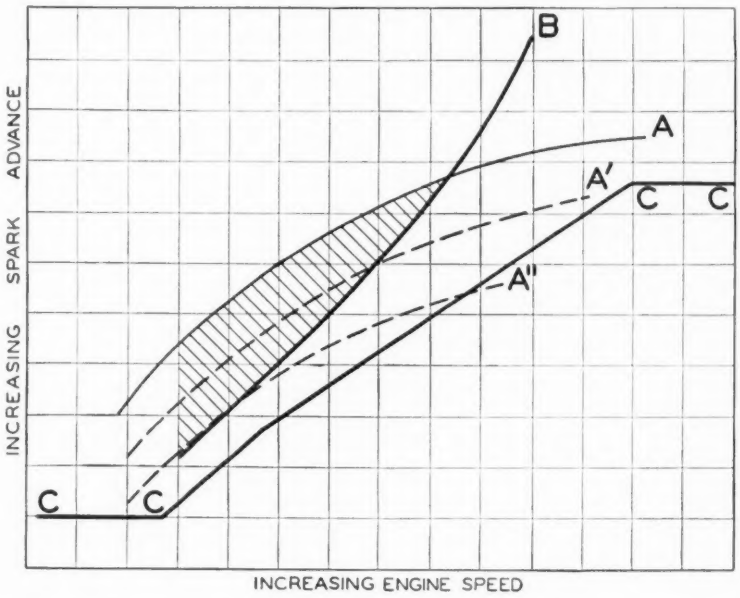


Fig. 4—Curves showing relationship between engine speed, spark advance and maximum power.

For any given fuel there is a definite spark advance at each speed, beyond which audible knock occurs. Curve B shows the spark advance which cannot be exceeded without producing audible knock for a specific fuel. This curve is called the curve for "borderline" knock. The shaded area is the range within which knock will occur if the spark is advanced with this fuel to give maximum power at each speed. The intensity of the resulting knock is indicated by the height of the shaded area at the corresponding engine speed.

Proper adjustment of the spark advance curve is generally considered to be that which brings it up to a position where it just makes contact with the curve for the fuel used; this is the closest approach possible with a given distributor, to the advance for maximum power, without detonation. Such an adjustment is made by rotating the distributor on the engine, which would move the whole curve C-C-C-C up or down to approach Curve B.

In addition to the static or basic ignition timing which is indicated by the flat portion at the beginning of the spark advance curve C-C-C-C, some consideration may have to be given to the spark advance-speed relationship (automatic spark advance) of the distributor itself. By means of changing the spring tension of the governor weights that control the automatic spark advance at the various engine speeds, the slope of the spark advance curve can be increased or decreased. As a general rule, this modification is not believed necessary at the present time with the majority of vehicles, but it may be a factor in any engine having initially poor distributor characteristics. Since distributor weight springs will weaken after a period of time, a thorough check should be made of the distributor before any ignition timing adjustments are made to relieve detonation.

Effect of Fuel

An investigation of the effects of fuels of a variety of octane numbers on the performance of a well-known bus and truck engine of 611 cubic inches displacement has resulted in some very interesting data. Referring to Figure 5, the effect of ignition timing, both static and in relation to engine speed, on the maximum power and octane requirement of this engine may be observed. Maximum power under full throttle operation expressed in terms of foot pounds of brake torque was first determined as a function of spark advance at various engine speeds for both rich and lean air/fuel ratios. The effect of these different carburetor jets will

be discussed later in connection with carburetor adjustments.

Operating under full-throttle conditions similar to those for which torque measurements were made, various fuels of known octane value were run. The spark was advanced to the point of incipient knock for each fuel at the various speeds. These data were then superimposed on the torque curves in Figure 5 and are shown as dotted lines representing octane requirements at that particular spark setting. In other words, operating at spark advances above the octane line in any instance produced knocking while operation at lower spark advances gave knock-free performance. For example using a fuel of 80 octane with the No. 59 carburetor by-pass jet, a spark advance of almost 40° B.T.D.C. was attained at 2200 r.p.m. before any knocking occurred.

The effect of spark advance-speed relationship (automatic spark advance) on the power and octane requirement of this particular engine was determined by comparing the performance on each of two different distributors. The spark advance curves for these distributors, designated as D and E, are superimposed on the torque and octane requirement curves in Figure 5. It should be noted that a static spark setting of 15° B.T.D.C. was employed for each distributor. An ideal relationship would exist if the distributor spark advance curve followed approximately the curve of "borderline" knock for the fuel to be used. If the distributor-advance curve exceeds the "borderline" knock curve at any speed, knocking will occur. Conversely, if the spark advance curve falls short of the "borderline" knock curve, the spark is unnecessarily retarded.

By this premise to obtain the maximum performance out of a given fuel the spark advance characteristics of the distributor should be adjusted if possible to follow closely the "borderline" knock curve of the fuel to be used.

Thus if in actual service knocking is experienced at a certain speed, it may be possible to adjust the spark advance characteristics of the distributor to eliminate knocking without retarding the static spark setting. Such an adjustment while eliminating knocking at this one speed, will not affect power at the other speeds such as would be the case where the static spark setting is retarded. Actually, it may be possible to advance the static spark setting where changes in distributor characteristics have been made to permit a closer approach to the "borderline" knock curve.

It would appear from Figure 5 that some improvement in the distributor spark advance curve could be made for use with the lower octane fuels. However, it should also be noted that the spark advance curve that is best for leaner air/fuel mixtures will not be the best for richer mixtures.

While the foregoing is applicable to some engines, other engines may not require such treatment and simple retardation of the static spark advance may be all that is necessary to eliminate knocking without large sacrifices in power. For example, Figure 6 shows the effect of spark advance on the power (determined as time to accelerate from 20 to 50 m.p.h.) and octane requirement of another bus engine under road-load conditions. It is apparent that for this engine a slight retardation of spark timing reduces octane requirement materially but at the same time the loss in power as indicated by the accelerating time is almost negligible in the range of present-day fuel changes.

In view of the foregoing information relative to adjustments in ignition timing, the fleet operator is probably desirous of further details regarding an adjustment procedure to insure a uniformly correct setting throughout his fleet. Accordingly, The Ethyl Gasoline Corporation* has suggested that the following procedure might be employed:

> "Because of a wide variety of physical characteristics of the ignition systems on the many makes and models of commercial engines, instructions on ignition timing must necessarily be general. The procedure in establishing the correct ignition timing on a given engine when lowered octane fuel is to be used is to load the vehicle to average gross weight and run road acceleration comparisons. These acceleration tests are made by advancing or retarding the spark one or two degrees after each set of runs until either a permissible knock level is reached or time required for acceleration begins to increase.
>
> "Acceleration tests can be made by using a stop watch, either to determine the length of time required to accelerate from 10 to 45 m.p.h. with wide open throttle, or the time required to accelerate at wide open throttle over a fixed distance, say 1,000 ft. Several runs should be made with each distributor setting and they should be made in both directions on a given course. All settings should be for permissible knock intensity. Trace to light knock should be the maximum permissible knock level for heavy duty commercial engines when using a knock intensity scale of from 'no knock' to 'heavy knock.' This scale should be divided as follows: 'no knock,' 'trace knock,' 'light knock,' 'medium knock,' and 'heavy knock' as determined by anyone with normal hearing.
>
> "It is difficult to establish an absolute knock intensity scale but by advancing and retarding the spark a person can familiarize

*Time to Retune—*Bus Transportation*, June, 1942.

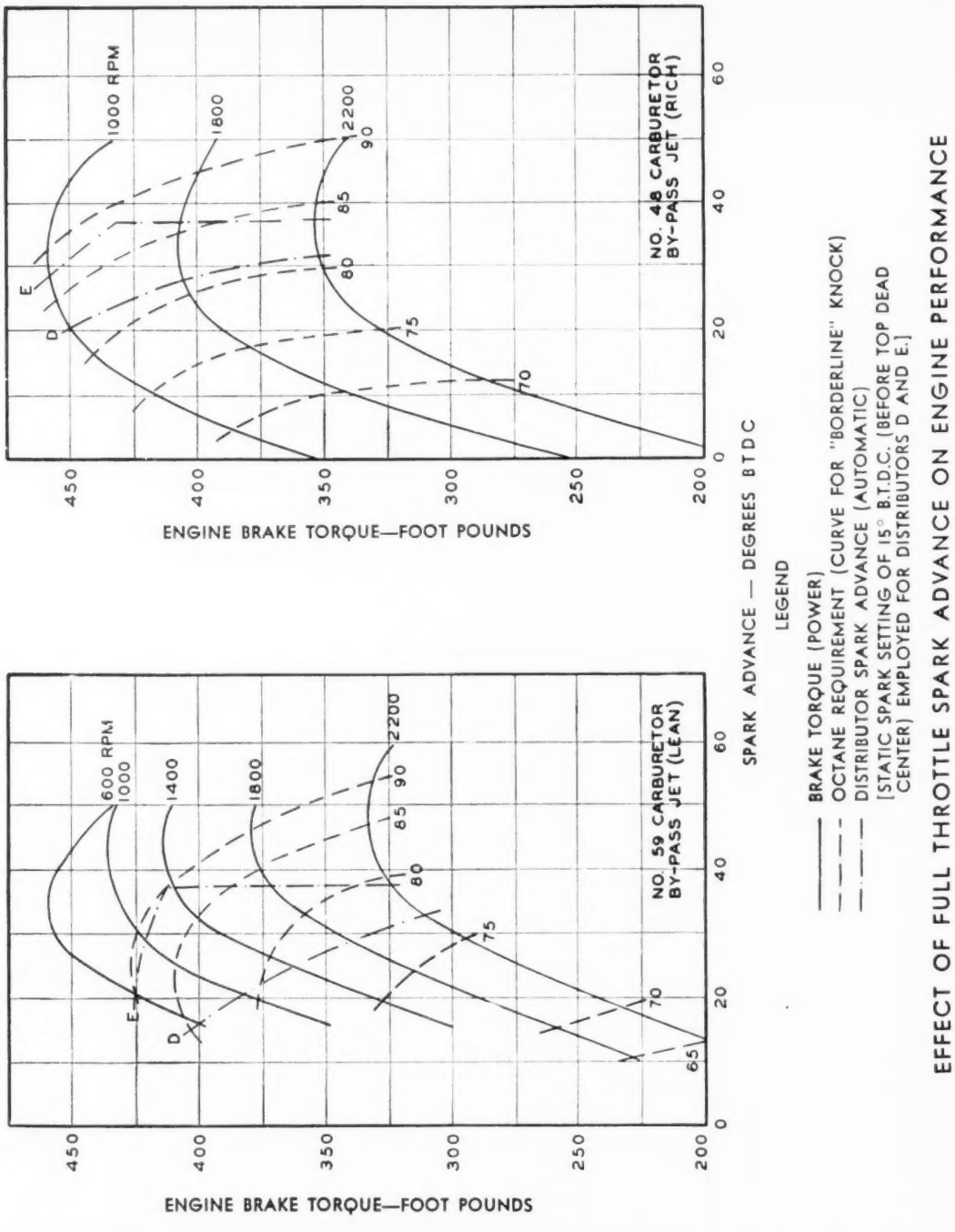


Fig. 5—Showing effect of full throttle spark advance on performance of a 611 cubic inches displacement engine.

himself with the full scale of knock intensity on an engine and, after this, he will be able to establish for himself the divisions of the knock intensity scale as described above. All knock intensity ratings should be done with as little sound insulation between the observer and the engine as possible. For instance, in rear engine buses, hatches at the rear compartments should be opened and the observer should be close to the engine.

"After the correct ignition setting is established for permissible knock with a given

fuel, this setting can be marked on the flywheel or convenient pulley wheel and all like engines in the fleet can be similarly marked. It is probably advisable to check ignition timing and establish knock level on more than one engine in a group and average the data before marking the flywheels on the entire group. It is also important to use engines for test that have a normal amount of carbon accumulation."

Following the establishment of the correct ignition timing, the carburetor idling adjustments will probably require resetting to regain proper idling speeds and normal engine smoothness.

Carburetor Adjustments

As pointed out previously, the full throttle power and octane requirement data on the 611 cubic inches displacement engine were obtained at both rich (No. 48 by-pass jet) and lean (No. 59 by-pass jet) air/fuel ratios. Again referring to Figure 5, it is evident that:

1. With the rich jet, engine torque or power is approximately 10% greater than with the lean jet.
2. With the rich jet, spark advance required for maximum power (and also for less than maximum power) is reduced by about 10°, thus permitting knock-free operation on a lower octane fuel.
3. At equal spark advances, the rich jet produces a higher octane requirement than the lean jet.
4. At equal power settings, the rich jet shows a lower octane requirement than the lean jet.
5. At spark advances for equal octane requirement, the rich jet produces greater power than the lean jet.
6. With the lean jet, spark retard is limited by backfiring to about 15° B.T.D.C. With the rich jet, satisfactory operation can be obtained to much more retarded spark settings.

From the foregoing, it appears that a substantial reduction in engine octane requirement might be attained by some enrichment of the full throttle mixture and corresponding retardation of the full-throttle spark advance on this particular engine. However, this method of reducing the octane requirement would increase full-throttle fuel consumption and unless the relative amounts of full-throttle, part-throttle, and idle operation are known for the particular engine service, the effect of this method on overall economy is difficult to estimate.

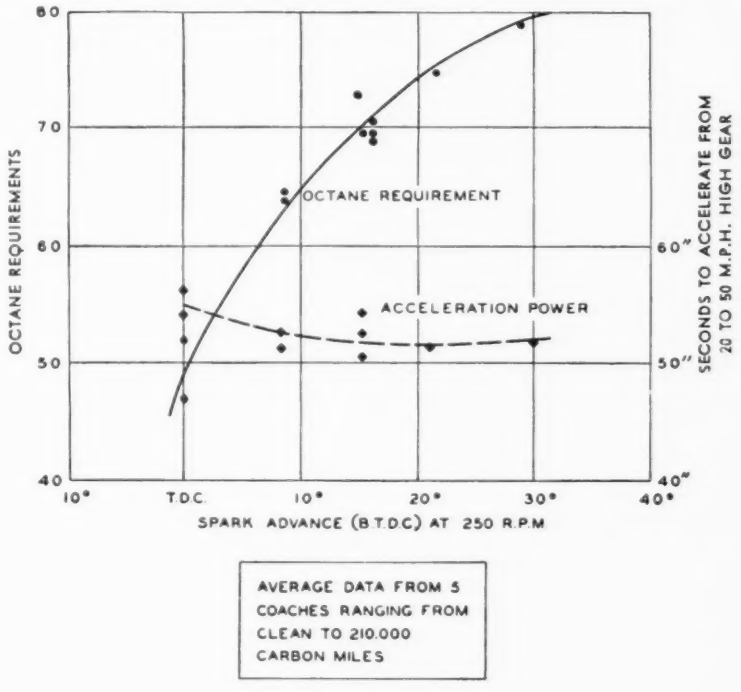


Fig. 6—Showing effect of spark advance on power and octane requirements.

Referring to Table 1, it is interesting to note that in the 70-80 octane range, the mixture enrichment causes no increase in specific fuel consumption even at full throttle, since it results in a power increase of approximately 20%. It may be assumed that if the engine is not continuously and excessively overloaded, the increase in power by mixture enriching should reduce the full-throttle operating time and thus offset any increase in overall fuel consumption.

Lowering Compression Ratio

This method of eliminating detonation should not be considered except in extreme cases and only as a last resort. The power and

economy losses are large since reducing compression ratio is directly contradictory to the improvements in engine performance achieved by the gradual increasing of this ratio over a period of years. At the same time the use of these additives has included both dynamometer and road testing. Finally, service tests in the field have proved the value of additives to a remarkable degree.

The benefits to the operator are measured in

TABLE 1
ENGINE PERFORMANCE — 1800 R.P.M.

Octane Number	Spark Advance °BTDC	Specific Fuel Consumption Pt./BHP-Hr.	Brake Torque Ft. Lbs.
	No. 59 Carbureter By-Pass Jet (Lean)		
70	15	0.95	260
75	24	0.80	315
80	33	0.71	360
	No. 48 Carbureter By-Pass Jet (Rich)		
70	10	0.93	335
75	18	0.82	380
80	26	0.71	405

parts and materials are involved which under present conditions may be considered critical. However, if this corrective measure is eventually required, it may be accomplished by installing thicker cylinder head gaskets, lower compression pistons or a redesigned cylinder head.

The use of two standard cylinder head gaskets should be considered with caution and the engine manufacturer consulted as to the efficacy of this arrangement. Most engine manufacturers have drawn up specific instructions regarding the measures to be taken for the relief of any detonation with their respective engines. Where further compression ratio reduction is necessary, replacement parts are offered or detailed sketches provided for machining piston heads. Since static ignition timing changes with a change in compression ratio, new spark settings will have to be determined when the compression ratio is changed in any engine.

ENGINE LUBRICATION

Heavy-Duty Motor Oils

Lubrication of the modern heavy-duty gasoline engine is affected by a variety of conditions, some contingent upon operation, others upon the mechanics or structure of the engine itself.

Quite naturally, the basic thought in maintenance is to prevent replacement of parts. Some wear must be expected in any type of heavy duty engine service, but if the limitations of materials are appreciated and the engine is in proper adjustment with excessive loading kept to a minimum, this wear should not go so far as to result in failure of bearings or piston rings.

Lubricating oils have been improved materially to meet the advance in engine design over recent years. Additives have been developed and evaluated. Laboratory research covering terms of greater mileages between overhauls, better mileage per gallon of fuel and lubricating oil and a reduction in cost of parts replacement and in frequency of overhaul.

There is a definite trend toward heavy duty oils which are of the detergent and dispersive type. Oils of this type containing carefully selected additives have proved in service the prediction of the research laboratories as to their protective ability especially under heavy duty engine service. A definition of the functions of detergency and dispersion is of interest:

Detergency is that characteristic of a motor oil which provides a cleansing or dissolving action on old, previously formed deposits in used engines, preventing their redeposition. In new engines, detergency will help prevent the initial deposition of such deposits.

Dispersion is that characteristic of a motor oil which enables finely divided, insoluble particles resulting from oil decomposition and fuel combustion products to be kept in a suspended state throughout the body of the oil. In an oil of poor dispersion qualities agglomeration or precipitation of these products occurs to form noticeable deposits on engine parts.

Inasmuch as a motor oil, containing an additive of detergent and dispersive qualities, is continually taking up more and more foreign materials (which have comparatively little or no lubricating value) during its course of circulation, ultimately it will become overloaded. Accordingly, the mistake should never be made of extending drain periods too long, otherwise some of the finely dispersed contaminants which have been taken up by virtue of the action of the additive may be deposited in vulnerable engine parts.

It is also important to remember that during the course of by-passing a certain amount of the oil through any of the conventional absorbent

type oil filters, some of the additive may be removed along with some of the non-lubricating impurities. This is another reason why the oil should be drained at regular intervals and the engine flushed before adding new oil.

This possibility of removal of additive applies also to many of the conventional methods of oil reclamation. Hence, a reclaimed motor oil which originally contained an additive of detergent and dispersive nature should not be depended upon as containing very much if any of this additive after it has been passed through the reclamation process.

This fact has given rise to the idea that it might be possible to add a new charge of additive in order to bring the oil back to its original characteristics. This is a dangerous procedure which should not be approached by the novice inasmuch as involved engine testing would be necessary to be insured of obtaining a product of proper quality. In all cases the additive must be suited to the hydro-carbon make-up of the oil.

It is not enough merely to mix straight mineral oil and any one of a number of additives which have been developed and expect to obtain an oil of detergent and dispersive characteristics. The oil industry has devoted intensive research for the past few years and has proved conclusively that there is a basic relationship between lubricating oils of various hydrocarbon make-up and the additives which have been adopted. This relationship cannot

TABLE 2*

COMPARATIVE PROPERTIES OF TIN-BASE, LEAD-BASE AND LEAD-SILVER-BASE BABBITTS

Alloy Type	Designation		Composition, per cent					Brinnell Hardness[1]				Ease of bonding	Ductility,[4] per cent
	Alloy No.	Spec'n.	Lead	Silver	Antimony	Tin	Copper	As Cast[2]	Aged[3]	Age and Test—300 deg. F. 30 Sec.	Age and Test—300 deg. F. 300 Sec.		
Tin Base	398	ASTM No. 2	—	—	7.5	bal.	3.5	19	17	6.0	4.4	—	99
	399	ASTM No. 3	—	—	8.3	bal.	8.3	20	20	7.2	5.5	—	91
Lead-Base	401	SAE No. 13	bal.	—	10	5	—	21	17	6.4	4.0	—	—
	403	SAE No. 14	bal.	—	15	10	—	26	18	6.5	4.2	—	53
	402	ASTM No. 8	bal.	—	15	5	—	22	17	5.8	3.7	—	—
	400	ASTM No. 10	bal.	—	15	2	—	21	16	6.4	5.0	poor	50
	407	ASTM No. 10	bal.	—	15	2	0.2	18	18	7.1	5.4	fair	40
Lead-Silver-Base	366	— —	bal.	5.1	15	—	0.2	22	16	6.0	3.8	—	—
	367	— —	bal.	5.0	15	2	0.2	23	21	8.9	6.6	good	40
	368	— —	bal.	4.8	15	5	0.2	25	19	7.2	5.9	—	57
	394	— —	bal.	4.8	15	5	—	22	18	6.9	4.7	—	77
	397	— —	bal.	2.6	10	3	—	21	18	7.2	5.2	good	59

[1]2.5 mm. ball, loads of 2 to 5 kgs. Load applied for 11 secs. except where otherwise specified.
[2]Hardness measured after 24 hrs. at room temperature.
[3]Aged for 24 hrs. at 300 deg. F.
[4]The ductility was measured by pounding down a specimen of standard size until cracking had occurred. The percentage reduction in thickness to cause this cracking is the figure given.

TABLE 3*

RESULTS OF UNDERWOOD CORROSION TESTS

Designation		Composition, per cent					Wt. Loss[1]—Gram	
Alloy No.	Spec'n. No.	Lead Pb	Silver Ag	Antimony Sb	Tin Sn	Copper Cu	Oil + iron naphthanate	Oil + oleic acid
398	ASTM #2	—	—	7.5	bal.	3.5	0.000	0.006
399	ASTM #3	—	—	8.3	bal.	8.3	0.000	0.002
403	SAE #14	bal.	—	15	10	—	0.000	0.002
364		"	6.0	—	—	—	0.084	0.324
367		"	5.0	15	2	0.2	0.002	0.003
397		"	2.6	10	3	—	0.003	0.014

[1]During 8-hr. test at 325 deg. F.

*Tables 2 and 3 taken from "Tin Conservation—Silver in Lead-Base Babbitts" by H. W. Gillett and R. W. Dayton. Battelle Memorial Institute, Columbus, Ohio. Pub. in Metals and Alloys, April, 1942.

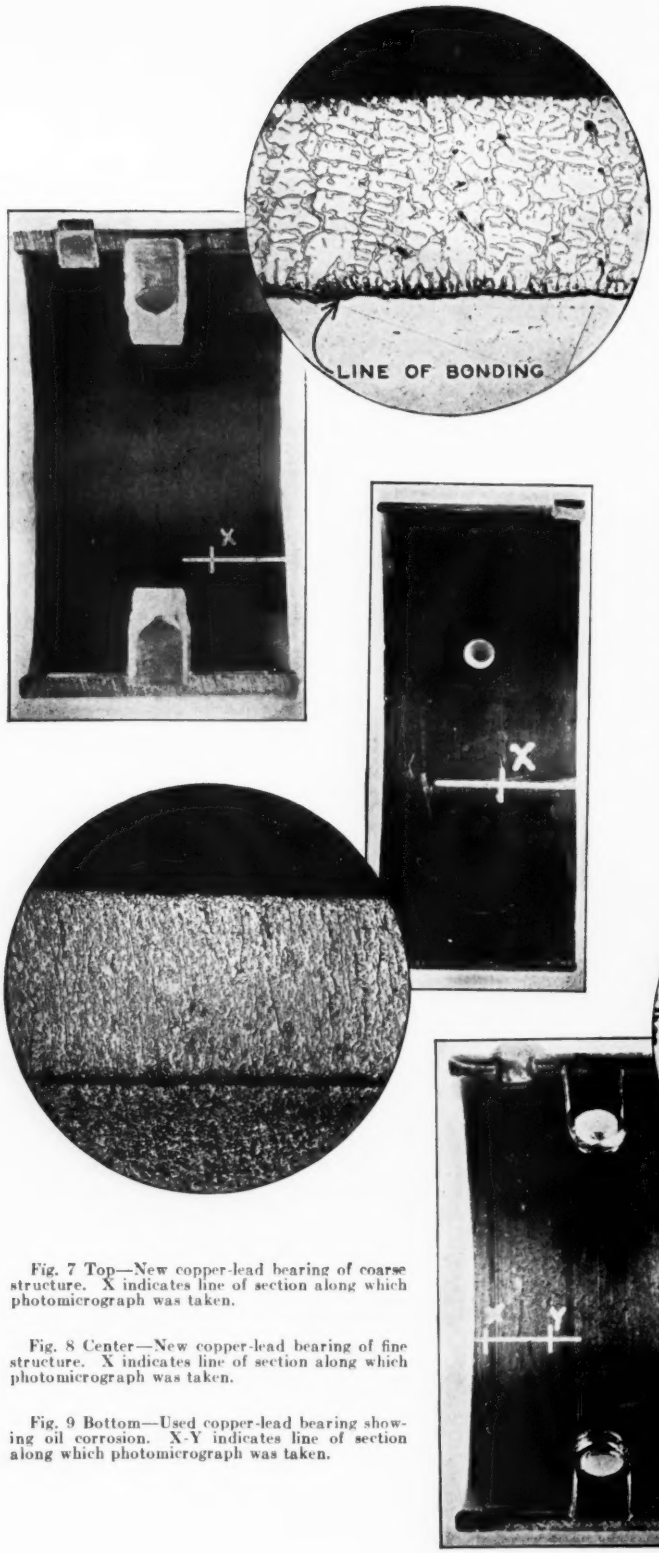


Fig. 7 Top—New copper-lead bearing of coarse structure. X indicates line of section along which photomicrograph was taken.

Fig. 8 Center—New copper-lead bearing of fine structure. X indicates line of section along which photomicrograph was taken.

Fig. 9 Bottom—Used copper-lead bearing showing oil corrosion. X-Y indicates line of section along which photomicrograph was taken.

be duplicated dependably simply by the process of mixing in the field. By the same token, a reclaimed oil in all probability will not give the same results with the same additive as were obtained with the originally compounded oil.

Bearing Metals

At the same time that heavy duty additive type oils are being improved, bearing metals are being actively studied by the metallurgists of the automotive industry, and the chemists of the petroleum industry. Limited availability of some components once more becomes a factor. Accordingly, when it is necessary to obtain replacement bearings, the metals available today must be given careful thought. Needless to say, the tin-base babbitts are virtually "out." Fortunately, alloys of cadmium, copper and silver have been developed which in many cases function better than tin-base babbitt in heavy duty service, due to their higher load-carrying capacity and hardness. (See tables 2 and 4.) Silver-alloys received special attention—silver being used

to replace the greater part of the tin. There has been developed recently a typical lead-silver-base babbitt predominating in lead, containing 5.0% of silver, 15.0% of antimony and 2.0% of tin. Research has indicated that such an alloy is from 20 to 25% stronger than a good tin-base or lead-base babbitt, possessed of high bondability and satisfactorily resistant to corrosion. (See tables 2 and 3.)

Cadmium-silver and copper-lead are other alloys which have been developed to replace the conventional tin-base babbitt in heavy duty automotive service. Cadmium as a component of bearing metals is relatively scarce as compared with copper. Hence, the copper-lead alloys are even more important.

In the copper-lead bearing a mixture of copper and lead is bonded onto a steel backing. Even distribution of lead throughout the copper is very important, the copper serving as matrix or background. It is interesting to refer to Fig. 7 and Fig. 8 which show photographs and photomicrographs* of new copper-lead bearings of coarse and fine structure respectively.

In the photomicrograph shown in Fig. No. 7, for example, the heavy black line indicates the line of bonding between the bearing metal and the steel backing.

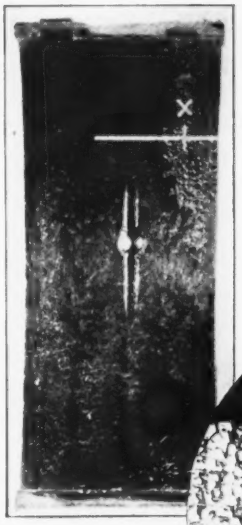
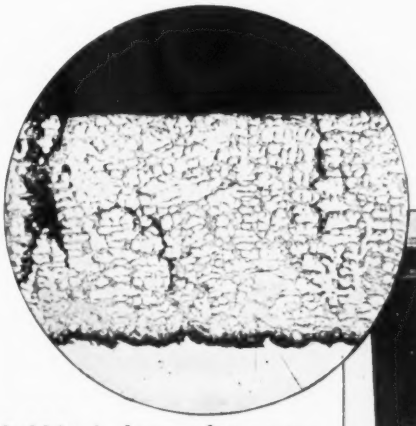


Fig. 10 Top—Used copper-lead bearing showing corrosion due to combustion products. X indicates line of section along which photomicrograph was taken.



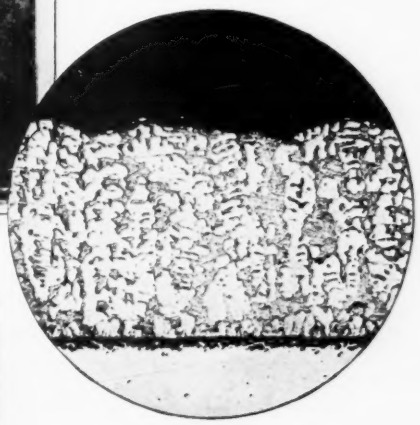
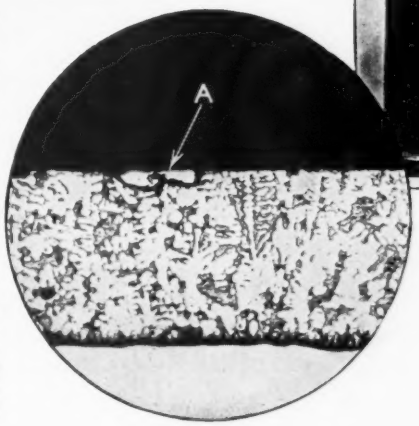


Fig. 11 Center—Used copper-lead bearing showing mechanical and fatigue failure. X-Y indicates line of section along which photomicrograph was taken.

Fig. 12 Bottom—Used copper-lead bearing showing at Point "A" particles of foreign matter imbedded in the bearing metal. X indicates line of section along which photomicrograph was taken.



*The method of photomicrograph study of bearings was developed by General Motors Corp. This method involves the sectioning of a portion of the bearing surface which is then polished and photographed through a microscope. This method of bearing study is of value to the operator and to the maintenance mechanic for the reason that it has enabled identification of many of the causes of bearing failures. In other words, after careful study of a set of photomicrographs an experienced engineer may be able to diagnose correctly the conditions which have caused failure of the bearings involved.

Above that is shown the mixture of copper and lead, the former being denoted by the white portions and the latter by the gray areas.

Unfortunately, however, all such bearings are subject to corrosion, the lead especially being susceptible to attack by certain acids which are formed when unstable oils are oxidized. This leaves a porous copper surface as indicated by the white areas of the photomicrograph in Fig. 9. As a result of this removal of the lead subsequent crumbling of the copper naturally may occur. Corrosion may often be promoted by by-products of fuel combustion which contaminate the lubricating oil in service. Fig. 10 shows a photomicrograph of the bearing structure of a copper lead bearing after attack by oil which has been contaminated by combustion products.

Bearing Failures

Granted that bearing failures will continue to occur with perhaps greater frequency than heretofore as commercial vehicle engines get older and accumulate more mileage it is well to study the means of identifying the cause, also what preventive measures should be taken.

Bearing failure can be regarded normally as being due to either mechanical failure or to oil corrosion.

Mechanical Failure may be due to the use of faulty materials, imperfect bonding of the bearing metal, overloading, overspeeding, out-of-round pins or journals (which may cause pounding), faulty or insufficient lubrication, contaminated oil, improper bearing installation, or insufficient bearing clearance. Mechanical failure can also be caused by detonation. In other words, detonation should not be permitted to continue for any length of time since irregularly heavy loads are imposed on the bearings, to cause premature fatigue failures.

Mechanical failures are indicated by actual cleavage of the bearing surface or by "hot spots" indicative of overloading or starved lubrication. A typical example of a failure owing to fatigued bearings is shown in Fig. 11.

Corrosion Failure is strictly a function of lubricating oil stability, and contamination with by-products from the combustion chamber and such other materials (water) as may accumulate in the crankcase and be circulated through the lubricating system. Corrosion may develop,

1. On the steel pins or journals in the form of a deposit such as rust due primarily to water and oxidation. This will tend to score the bearing surface, or
2. In the form of bearing metal removal due to the dissolving effects which certain acids have upon lead and copper. Normally the lead is more easily dissolved by these acids.

TABLE 4*

FIELD OF USEFULNESS OF VARIOUS BEARING METALS

Bearing Metal	Max. unit pressure, psi	Minimum Zn P (1)	Maximum PV (2)	Max. oil reservoir temp, F	Minimum journal hardness, Brinell	Corrosion
Tin-base babbitt Copper 3–50 Antimony 7–50 Tin 89–00 Lead (max.) 0–25	1000	20	35,000	235	Not important	No
Lead-base babbitt Tin 5–7 Antimony 9–11 Lead 82–86 Copper (max.) 0–25	1800	10	40,000	225	Not important	No
Cadmium-silver-copper Silver 0–75 Copper 0–50 Cadmium 98–75	1800-3850	3–75	90,000 and over	260	250	Not likely if specified temp is maintained and proper lube oil is used
Copper-lead Copper 35–00 Lead 65–00	Over 1800	3–75	90,000 and over	260	300	Same as above

Compiled as a guide for automobile engine design. (1) Z = absolute viscosity of oil at operating temperature, n = rpm of journal, P = maximum total load on bearing. (2) V = peripheral velocity of journal, fpm.

*From "No More Straits Tin For Your Bearings." Pub. in Power, May, 1942.

Corrosion failures due to lead removal are often indicated by small pits or cavities in the bearing surface, denoting that lead (and some of the copper) has been actually etched away. In extreme cases a general lowering of the bearing surface over a relatively large area will be observed.

Bearing Replacement

Regardless of the bearing metal, in the replacement of automotive engine bearings today, more care than ever should be given to study of conditions which may have contributed to the failure which requires this replacement. Photomicrographs of the failed bearing are extremely valuable in diagnosing the cause of failure. In addition from a mechanical point of view one should investigate:

1. Roundness of the crankpins and journals and the extent of wear which may have developed.
2. Alignment of the crankshaft.
3. Extent to which dirt has penetrated the crankcase and/or oiling system.
4. Adjustment and tightening of the bearing caps.
5. Extent of bearing clearances.
6. Crankcase oil temperatures.
7. Suitability of the lubricating oil.
8. Length of time which is allowed to occur between crankcase drains.
9. Over-all engine temperatures.
10. Type of service and loads imposed.

A clean engine with all parts in proper alignment and no out-of-round pins and journals will impose the least load on the bearings and enable the lubricating oil to give most positive protection.

At all times it is of utmost importance to be sure that the oil has not become unduly contaminated by foreign material. An example of how a bearing surface may be so affected is shown in Fig. No. 12. Point A indicates how foreign matter may become imbedded in the bearing surface so as to exert scoring action upon the shaft.

Controlling Bearing Temperature

Engine bearing temperatures are controlled partly by the cooling effect of the crankcase oil, partly by the cooling water system, and partly by radiation or air cooling of the crankcase. Here again we are confronted with the use of priority materials, i.e., rubber in the hose connections and tin in the solder used in the radiator assembly. Immediately, this imposes the obligation to conserve these materials in service and to use them sparingly when repairs must be made.

Control of engine bearing temperatures becomes all the more important with the return of the cast iron piston which involves heavier crankpin, piston pin and main journal bearing loads and the use of bearing materials which may be subject to corrosion if bearing temperatures run too high.

Control of engine bearing temperatures by the cooling effect of the oil is also influenced by the rate of oil circulation over the bearing surfaces. In order to become an effective coolant, the oil must circulate freely throughout the lubricating system. This means that bearing clearances must be adequate, but never so excessive as to promote pounding of the pins or journals. With harder type bearing metals the modern theory is to provide for a clearance of some 0.001″ per inch of shaft diameter.

The rate of oil circulation is influenced also by the capacity of the oil pump. Insufficient oil pressure affects both the quantity and rate of oil flow at the bearing surface.

Suitable oil grooving of the bearing facilitates oil circulation. Conversely, if the oil grooves become clogged with gummy foreign matter, they are worse than no grooves at all. Hence, the necessity for clean oil and a clean engine. Oil grooves reduce the effective bearing area so they should not be cut without due consideration of the length-diameter ratio and the probable maximum load. As this latter will increase when cast iron pistons are to be installed, it is obvious that these matters of clean oil, bearing clearance, bearing metal, grooving and change in load are all closely inter-related.

When it is necessary to install new bearings at the time of overhaul, correct fitting of the shells should be insured; undersize bearings should be considered where crankshaft journals, etc. are worn; and tension wrenches should be used to equalize the stress on all bolts to insure even fitting of the caps.

Piston Composition

Until about ten years ago, the cast iron piston predominated. Then the automotive engineer designed the aluminum piston as it functioned better in the high-speed engine, the lighter weight imposing less load on the connecting rod and piston pin bearings. He still continued, however, to use the cast iron piston ring. Now, he is faced with the necessity of reverting to the cast iron piston due to military requirements for aluminum.

It is of interest to review how this procedure may be related to lubrication. Largely, it becomes a matter of considering the unit load on the bearings due to increased weight. On an average, a cast iron piston will weigh from 50% to 100% more than an aluminum piston of similar design and dimensions. When a cast iron piston is installed in a modern heavy duty engine equipped with bearings of conventional

thickness, it is conceivable that the increase in unit load may lead to increased bearing wear, especially if the crankpins or piston pins are slightly out of round. The cleanliness of the oil film is also a factor. If the oil filter is loaded with dirt and metallic particles to such an extent as to allow similar material to accumulate in the crankcase, its circulation with the oil film may increase the rate of wear.

There are arguments both for and against the use of a heavier oil under such conditions. Using an SAE 50 instead of a 40 oil may provide somewhat more of a cushioning effect, but if there is an excess of dirt it will free itself less readily of contaminants than the lighter oil. So the efficiency of the oil filter must be considered at the same time.

In planning to replace aluminum pistons with cast iron pistons, the original design of the engine should be changed as little as possible, to enable inter-changeability of other parts as operation may require. Fortunately, this will become more and more practicable as foundries perfect their methods of casting so as to reduce the ultimate weight of the finished pistons. The problem is to cast thin sections to low tolerances; then the weight-difference will be decreased.

Effect on Oil Consumption

Review of available research data indicates that substituting cast iron for aluminum pistons in an existing engine will have no material effect on the oil consumption, provided the new pistons and rings are fitted properly and permitted to seat themselves during an adequate breaking-in period.

SLUDGE

Sludge must be considered in connection with bearing clearances, bearing composition, oil grooves and the cleanliness of the engine. Sludge formation is closely allied with engine cooling. Improper temperature control is an active contributing factor.

Sludge as developed in the automotive engine is broadly classified as being of:

(a) Petroleum nature, resulting from high engine temperatures which promote oil breakdown or oxidation, and

(b) Mechanical nature, developed at low operating temperatures from water emulsification due to moisture condensation and unburned or partially burned fuel particles, also the accumulation of road dust or metallic particles when wear has occurred.

Oil-Tar Sludge

The formation of oil-tar sludge is promoted by slow oxidation, which develops accumulations of tarry matter in the crankcase when the oil is exposed to high temperatures and excessive aeration. Consequently it is accelerated when an unstable oil is exposed to high temperature, and intimate contact with air. The preventives are to use an oil of good chemical stability, and to reduce the oil temperatures.

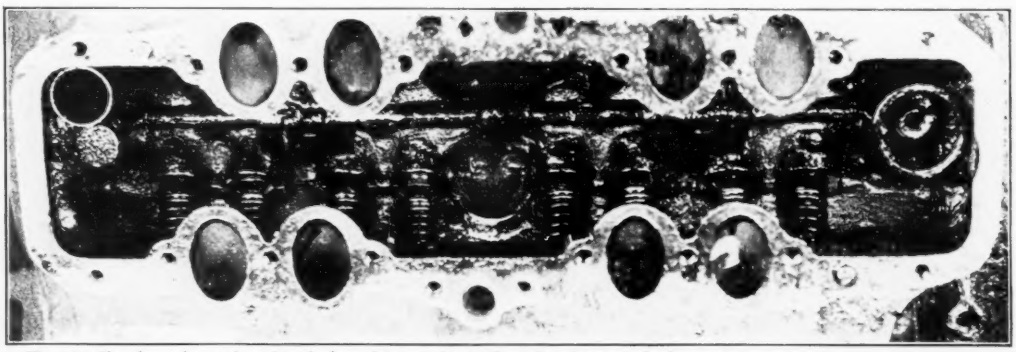


Fig. 13—Showing a formation of typical emulsion sludge in the valve chamber of a heavy duty engine.

Oil-Carbon Sludge

Oil-carbon sludge is composed of a mixture of oil and carbon. The carbon originates in the combustion chamber or on the upper portion of the cylinder walls from thermal decomposition of the lubricant and/or incomplete combustion of the fuel. Resultant contamination of the crankcase oil occurs when piston ring blow-by takes place.

Thermal decomposition involves breakdown of petroleum products by temperature. Under the high temperatures encountered in the combustion chamber, fuel and lubricating oil combine with oxygen from the air to form carbon dioxide and water, but any carbonaceous material which is not oxidized or burned may stay behind in the engine. This is confirmed by analysis of deposits from the combustion chamber which are found to be made up almost entirely of hard carbon and mineral matter.

Oil-carbon sludge is also formed under idling

and low power output conditions at low operating temperatures. Often it is most severe under these conditions.

Emulsion Sludge

Emulsion-sludge is formed in the presence of an excess of water. Under high temperatures it can change to oil-tar or oil-carbon sludge if the water content evaporates off.

All oils when contaminated with by-products of combustion or unstable hydrocarbons, will sludge when in contact with water. In other words, the emulsifying tendency of used oils, is largely dependent on the amount of contaminants present. Consequently, keeping the oil comparatively clean by means of a suitable oil filter is good insurance against formation of an excess of mechanical or emulsion sludge.

Appearance

The nature and appearance of crankcase sludge will vary according to the type of operation. In some cases it will be thick and sticky (oil-tar sludge)—indicative of oxidized oil as previously stated. In others, it will be in the form of an emulsion formed by water from condensation in the crankcase. The extent of such emulsions varies with the service. On long runs at high speed with normal jacket temperatures it will be almost negligible; when frequent starts and stops occur and low speed running prevails with considerable idling and low jacket temperatures, sludge emulsions may become very troublesome. A water-absorbing filter is an adjunct in such service.

Oil-carbon sludge may be thick and sticky, like oil-tar sludge; or, it may be fairly fluid. It is always black in color, however; whereas oil-tar sludge may be brown or black.

Points Where Sludge Is Most Severe

Crankcase sludge is most serious when it accumulates on the oil pump intake screen, in the piston ring grooves and in the oil lines. Sludge deposits on the oil pump screen or in the oil lines interferes with complete circulation of lubricating oil. Sludge in the ring grooves interferes with free motion of the piston rings, and sludge in the oil control rings increases oil consumption. Sludged valve chambers cause sluggish or sticking valves.

Conditions Which Can Control Sludge

For all practical considerations, straight petroleum oils do not oxidize at atmospheric temperature. Under the influence of heat, however, hydrocarbons will react with oxygen to form sludge. For every 25 degrees Fahr., of temperature rise, the rate of oxidation is approximately doubled.

Oil Temperatures

The oil temperature can be reduced as follows: the oil sump capacity can be increased; a less viscous oil used; or, an oil cooler installed. High oil temperature may be due to overloading, a hot running bearing or piston, insufficient water cooling or to excessively retarded spark, lean mixture ratios or detonation.

Fig. 14—Showing a sludged oil pump screen. Deposits of this nature can cause considerable engine failure.

Hot Spots

Where hot spots exist as on the underside of pistons, either the amount of oil striking such a surface should be kept to a minimum or a considerable volume of oil should be thrown against the hot spot. The advantages of flooding hot spots with oil are that the oil will cool the surface, and none of the oil will be increased in temperature appreciably.

Jacket Temperatures

The water jacket temperature may affect the formation of some types of sludge. For example, decreasing this temperature may reduce the amount of oil-tar sludge and increase the amount of oil-emulsion sludge. If oil-carbon and oil-emulsion sludge are high, however, due

to low temperatures caused by idling and low power output, increasing the jacket temperature will have a beneficial effect.

Operating conditions are also contributory as when taking a bus or truck from a heated garage and putting it into immediate operation in cold weather without warming up the engine.

Crankcase Ventilation

Sludge is always likely to form in engines where crankcase ventilation is completely absent or where its installation is ineffectual. Proper ventilation of the engine crankcase helps to remove any water vapors which may condense to form oil emulsion sludge. In addition, crankcase temperatures are maintained at a more normal level particularly if considerable blow-by is occurring. Attention should be given to keeping the filters on the air intake pipes clean. Deposit accumulations in the crankcase ventilation piping system should also be removed frequently.

Precautionary Measures

Use a stable sludge-resistant oil.

Use good oil filters and replace elements regularly.

Be sure engines operate at an efficient temperature, i.e., with water temperatures from 160 to 180 degrees Fahr.

Be sure adequate crankcase ventilation is employed and operating.

Drain and flush crankcases regularly.

Store vehicles in heated garage in winter, when temperatures are low, so that the amount of moisture condensed in the crankcase will be kept to a minimum. If necessary to store outdoors, more frequent crankcase draining will be required.

Air Cleaners and Oil Filters

Air cleaners must be kept clean and oil filter elements replaced at regular intervals if they are to serve their intended purpose and keep the engine clean. This becomes all the more important due to the present trend towards thinner bearings, closer engine clearances and higher speeds. It is obvious that parts may become seriously worn, and clearances altered markedly, if abrasive materials are circulated with the oil. A tin-base babbitt bearing surface often can absorb and retain some of such foreign matter without any appreciable harm to itself. It is questionable, however, to what extent, if any, this may occur in a copper-lead or cadmium-silver bearing the surface hardness of which is much greater than that of the softer babbitt bearings in order to withstand the increased loads and speeds.

CONCLUSION

Until Pearl Harbor, when rubber was still plentiful and gasoline was still available in unlimited volume, maintenance was just a routine procedure to the fleet garage foreman, occasioned by factors often beyond his control, such as careless drivers and just natural wear and tear. However, he had all the spare parts he wanted, usually enough labor and lots of time. So, when a bus or truck engine was scheduled for overhaul, it was seldom slighted and when the work was done the engine was good for upward of fifty thousand or more miles.

No wonder he was dazed when priorities developed, when tin, rubber, aluminum and copper were no longer available for the asking at pre-war prices. He had to carry on—but how? Automotive authorities immediately launched a campaign of discussion and instruction in the trade press. Most of them were practical for they were graduates of the research and road test schools. They developed substitute bearing metals, pistons, etc., all but a substitute for that vital chemical which gives knock-free performance under intensive road driving—tetraethyl lead—for it too became a priority material—for military purposes.

So, the truck and bus must carry on, using gasoline of slightly lower octane rating. Perhaps its engine will produce a little less power and consume more gasoline in the elimination of knocking; without a doubt, more frequent engine cleaning will be necessary, but certain factors in maintenance and adjustment will lessen the potential headaches.

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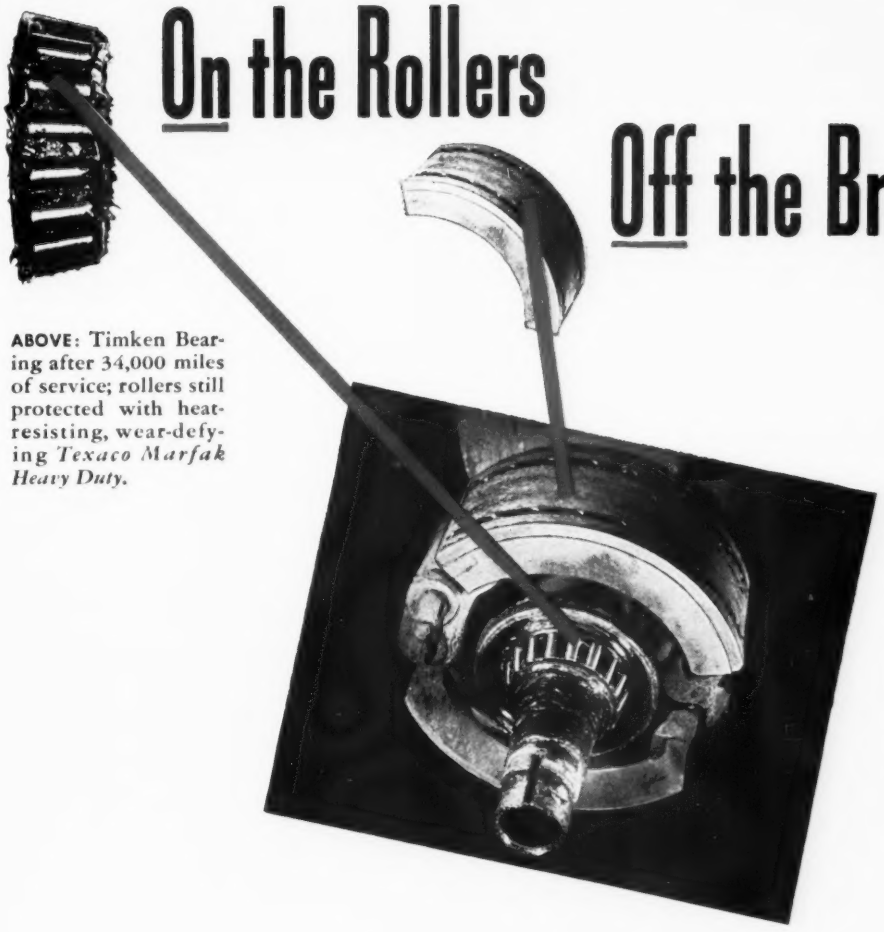

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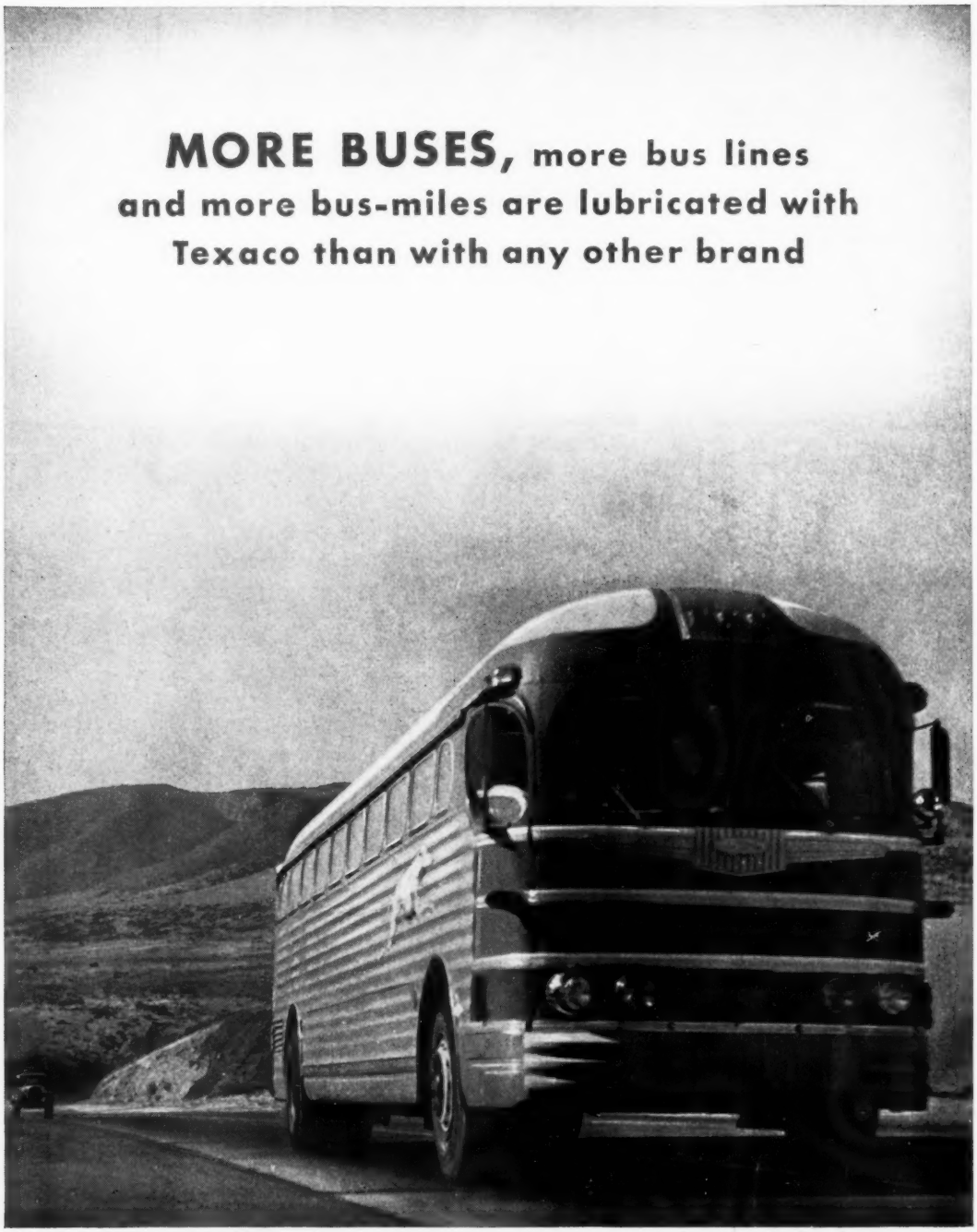

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